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Jeffrey A. Simmen, Principal Investigator
Applied Physics Laboratory
University of Washington

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ABSTRACTS AND AGENDA

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2nd International Conference on Shallow Water Acoustics
Grand Hyatt Hotel, Shanghai

AGENDA

Thursday, 17 September 2009

9:00 – 10:00	**OPENING REMARKS**
	Jeffrey Simmen, *Applied Physics Laboratory–University of Washington*
	Jing Tian, *Institute of Acoustics, Chinese Academy of Sciences*
	Ellen Livingston, *Office of Naval Research*
	Renhe Zhang, *National Laboratory of Acoustics, Chinese Academy of Sciences*
10:00 – 10:30	Break
	PROPAGATION I
10:30 – 10:45	Mohsen Badiey *Influence of internal waves on acoustic wave propagation on the New Jersey continental shelf*
10:45 – 11:00	Arthur B. Baggeroer *Prufer transformation methods for determining normal modes of ocean acoustics*
11:00 – 11:15	Kyle M. Becker *Accounting for water column variability in shallow-water waveguide characterizations based on modal eigenvalues*
11:15 – 11:30	Ching Sang Chiu *Observation and modeling of acoustic signal intensity fluctuations in the northeastern South China Sea shallow waters*
11:30 – 11:45	Nicholas P. Chotiros *Wave propagation in water-saturated sand and grain contact physics*
11:45 – 12:00	Alec J. Duncan and Li Fan *The effect of range dependence on the propagation of low frequency sound in shallow water over a limestone seabed*
12:00 – 1:30	Lunch
1:30 – 1:45	Dazhi Gao and Ning Wang *Dispersionless transform and signal enhancement application*
1:45 – 2:00	Tao Hu, Li Ma, and Yunpeng Zhang *Nonlinear internal wave behavior at south of Hai-nan Island and simulating their effect on acoustic propagation*
2:00 – 2:15	Boris Katsnelson and Mohsen Badiey *Theory and modeling horizontal refraction in shallow water*
2:15 – 2:30	David P. Knobles *The nature of sound propagation on the New Jersey continental shelf: Analysis of acoustic measurements taken during SW06*
	INVERSION I
2:30 – 2:45	Michael J. Buckingham *Geo-acoustic Doppler spectroscopy: a novel acoustic technique for surveying the seabed*
2:45 – 3:00	Yonggang Guo, Zaixiao Gong, and Fenghua Li *Geoacoustic inversion using towed line array and ship noise based on near-field MFP*
3:00 – 3:30	Break
3:30 – 3:45	Ross Chapman and Yong-min Jiang *Geoacoustic inversion in a spatially and temporally variable shallow water environment*

3:45 – 4:00	Yong-Min Jiang and Ross Chapman *Estimating marine sediment properties in a temporal varying water column environment*
4:00 – 4:15	Fenghua Li, Mei Sun, and Renhe Zhang *Analysis of sound fields recorded with vector sensors*
4:15 – 4:30	Jianlong Li, Wen Xu, and Liling Jin *Inversion of ocean environmental variations via time reversal acoustics*
4:30 – 4:45	Jianheng Lin, Baoyou Yin, and Xuejuan Yi *Geo-acoustic inversion using shallow water ambient noise and analysis of uncertainty*
4:45 – 5:00	Fuchen Liu and Shihong Zhou *Inversion of bottom properties based on ship-radiated noise received by a towed horizontal array*
5:00 – 5:15	Licheng Lu and Li Ma *Matched-field geoacoustic inversion by inverting ship-noise data*
5:15 – 5:30	James H. Miller and Gopu R. Potty *Geoacoustic measurements and tomographic inversions in the East China Sea and on the New Jersey Shelf*

Friday, 18 September 2009

SIGNAL PROCESSING

8:00 – 8:15	Fengxiang Ge, Yan Zhang, Zhenglin Li, and Renhe Zhang *Adaptive bubble pulse cancellation and its applications*
8:15 – 8:30	Chen-Fen Huang *Statistical estimation of source location in the presence of geoacoustic inversion uncertainty*
8:30 – 8:45	Ning Jia, Zhongyuan Guo, Jianchun Huang and Geng Chen *An improved passive phase conjugation array communication algorithm*
8:45 – 9:00	ChunXiao Li and XianYi Gong *Joint coherent time-reversal processing and incoherent diversity for distributed target detection in shallow water*
9:00 – 9:15	Yidi Ruan and Xianyi Gong *Target detection by receiving-transmitting-united MVDR TRBF under environmental mismatch*
9:15 – 9:30	Bingwen Sun and Shengming Guo *An experiment on passive synthetic aperture time reversal communications in shallow water*
9:30 – 9:45	Ling-ai Tian, Shihong Zhou, and Fuchen Liu *Extraction of the waveguide invariant from a shallow water acoustical experiment*
9:45 – 10:00	Dejun Wang and Fenghua Li *A robust separating and tracking method on two wideband sources by subspace rotation with one vector hydrophone*
10:00 – 10:30	Break
10:30 – 10:45	Shengjun Xiong and Shihong Zhou *Spread-spectrum acoustic communication*
10:45 – 11:00	Yan Zhang and Fenghua Li *Active matched-field localization by a horizontal line array*
11:00 – 11:15	Yanjun Zhang, Fenghua Li, and Xiaoxing Su *Improvement of longitudinal correlation of explosive signals by using waveguide invariance*
11:15 – 11:30	HangFang Zhao, XianYi Gong, and ZiBin Yu *Uncertain field modeling and robust source localization in shallow water*

REVERBERATION & TARGET SCATTERING

11:30 – 11:45	Zhengliang Cao, Shuanping Du, Shihong Zhou, Qianliu Cheng, and Fangyong Wang *Scattering from finite cylindrical targets in a horizontally stratified waveguide*
11:45 – 12:00	Xin-Yi Guo, Guo-Qing Wu, and Li Ma *Signal recovery technique based on the physical method of underwater acoustics*

12:00 – 1:30	Lunch
1:30 – 1:45	Finn B. Jensen and Mario Zampolli *Finite-element modeling in ocean acoustics: Where are we heading?*
1:45 – 2:00	Zhenglin Li, Renhe Zhang, and Fenghua Li *Coherent reverberation model based on adiabatic normal modes in a range-dependent shallow water environment*
2:00 – 2:15	Yongwei Liu, Qi Li, Dejiang Shang, Chao Zhang, Rui Tang, Dajing Shang, and Mengying Chen *Low frequency volume reverberation measurements in turbid seawater*
2:15 – 2:30	Henrik Schmidt and Wenyu Luo *Three-dimensional propagation and scattering around a conical seamount*
2:30 – 2:45	Jinrong Wu, Erchang Shang, and Tianfu Gao *A shallow water reverberation model based on bottom reflection parameters*
2:45 – 3:00	Shi-e Yang *Distant bottom reverberation in shallow water*
3:00 – 3:15	Yingzi Ying and Li Ma *T-matrix formulation of scattering by an obstacle near a planar sediment boundary and application to detection using iterative time reversal*

Saturday, 19 September 2009

MISCELLANEOUS TOPICS

8:00 – 8:15	Grant Deane *Physical mechanisms underlying the generation of ambient noise by whitecaps*
8:15 – 8:30	Xin-Yi Guo, Guo-Qing Wu, and Li Ma *Signal recovery technique based on the physical method of underwater acoustics*
8:30 – 8:45	Zhengyao He and Yuanliang Ma *Studies of the characteristics of a densely-coupled array of underwater acoustic transmitting transducers*
8:45 – 9:00	Fan Li, Sheng-ming Guo, and Yao-ming Chen *Sonar detection range index estimation approach in uncertain environments*
9:00 – 9:15	Hao Lu, Hai-bin Wang, Abdeldjalil Aissa el Bey, and Ramesh Pyndiah *Underwater time service and synchronization based on time reversal techniques*
9:15 – 9:30	Kun Liu and Shihong Zhou *Sound velocity fluctuation due to linear internal waves in the northern Yellow Sea*
9:30 – 9:45	Dayong Peng, Tianfu Gao, Juan Zeng, Haijun Liu, Haifeng Li, and Wenyao Zhao *Single-mode close-loop excitation in shallow water using two vertical hydrophone arrays*
9:45 – 10:00	Jie Yang, Ji-Xun Zhou, and Peter H. Rogers *Data-model comparisons for wind-generated surface waves from the ASIAEX East China Sea Experiment*
10:00 – 10:30	Break

INVERSION II

10:30 – 10:45	Martin Siderius *Acoustic remote sensing of the seabed using ambient noise*
10:45 – 11:00	Lin Wan, Ji-Xun Zhou, and Peter H. Rogers *Low-frequency seabed sound speed and attenuation inversion using explosive sound source signals in the Yellow Sea*
11:00 – 11:15	Kunde Yang, Yuanliang Ma, Xuegang Li, and Haibin Qiu *An inversion method of geoacoustic properties based on a towed tilted line array in shallow water*
11:15 – 11:30	Yanxin Yu and Zhenglin Li *Sound speed profile inversion in shallow water using a parallel genetic algorithm*

11:30 – 11:45	Ji-Xun Zhou and Xue-Zhen Zhang *Effective geophysical parameters for seabed geoacoustic models from low-frequency measurements*
11:45 – 12:00	Xian Zhu, Zhongkang Wang, and Huiliang Ge *An approach to measure the acoustic impedance of sediment in shallow water based on multi-path theory*
12:00 – 1:30	Lunch

PROPAGATION II

1:30 – 1:45	Peter H. Dahl and Jeewoong Choi *Observations of 0th order head waves in the Yellow Sea*
1:45 – 2:00	Fenghua Li and Renhe Zhang *Sound horizontal correlation and its effect on beamforming*
2:00 – 2:15	Ju Lin, Huan Wang, and Junping Sun *Effect of the tidal internal wave field on shallow water acoustic propagation*
2:15 – 2:30	Jin-Yuan Liu, Shih-Feng Yang, and Chen-Fen Huang *Uncertainty analysis of transmission loss in a very shallow water environment in the SiTzi-Wan Marine Test Field*
2:30 – 2:45	Jinzhong Liu, Ning Wang, and Dazhi Gao *Forward coupling of normal modes in ocean acoustic tomography*
2:45 – 3:00	James Lynch, Y.T. Lin, Tim Duda, Art Newhall, and Glen Gawarkiewicz *Acoustic ducting, refraction, and shadowing by curved (funky) internal waves in shallow water*
3:00 – 3:30	Break

PROPAGATION III

3:30 – 3:45	Zhaohui Peng, Lujun Wang, and Zhenglin Li *The effects of a sloping bottom on the vertical correlation*
3:45 – 4:00	Shengchun Piao and Qunyan Ren *Investigation of interference phenomena of broadband vector acoustic signals in shallow water*
4:00 – 4:15	Michael B. Porter *Gaussian beam tracing for ocean acoustics*
4:15 – 4:30	Yun Ren and Lixin Wu *The effects of source-receiver range and sound speed STD on the acoustic correlation time in the South China Sea*
4:30 – 4:45	Dajun Tang *Overview of mid-frequency sound propagation in the Shallow Water 2006 experiment*
4:45 – 5:00	Eric I. Thorsos, Frank S. Henyey, W.T. Elam, T. Brian Hefner, Stephen A. Reynolds, and Jie Yang *Transport theory for shallow water propagation with rough boundaries*
5:00 – 5:15	Ning Wang and Hao Zhong Wang *Extension of the coupled-mode method to waveguides with an elastic bottom*
5:15 – 5:30	T.C. Yang *Temporal coherence of normal modes in an ocean waveguide*

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ABSTRACTS

Influence of internal waves on acoustic wave propagation on the New Jersey continental shelf

Mohsen Badiey
College of Earth, Ocean, and Environment, University of Delaware, Newark, Delaware 19716

Experimental observations and theoretical analysis of sound propagation, including acoustic phase front fluctuations measured by a Vertical and Horizontal Line (VHLA) array (L-shaped array), are presented. Low frequency broadband signals were transmitted by bottom moored sources placed at the distance of ~25 km from the VHLA. In addition, a J15 mobile sound source moving with the passing internal waves transmitted various acoustic signals at different bearings and ranges to the VHLA. During the time period 18:00–22:00 GMT on 17 August 2006 a train of internal solitons traveled across the fixed source-receiver acoustic track. The mobile source on research vessel R/V *Sharp* was kept at a constant water depth moving in the horizontal plane with the advancing internal wave front. This internal wave packet, named Event 50, was also recorded by the R/V *Oceanus* radar a few kilometers away. The reason for placing the sound source on the advancing IW front was to examine the effects of azimuthal variability of the waveguide on the intensity fluctuation and acoustic propagation. A detailed transition of the waveguide as the internal wave progressively occupied the acoustic propagation track between the source and receiver is reported. It is shown that the intensity peaks at a small angle between the acoustic track and the internal wave front where sound intensity focusing and defocusing occurs. [*Work supported by ONR 321OA.*]

Prufer transformation methods for determining normal modes of ocean acoustics

Arthur B. Baggeroer
Department of Mechanical Engineering_and_Department of Electrical Engineering and Computer Science,
Massachusetts Institute of Technology, Cambridge, MA 02139

The Rayleigh–Helmoltz equation is key to modeling acoustic propagation. Numerical solutions are abundant and are imbedded in many modeling codes. This method is different as it takes a second order differential equation and converts it into two nonlinear equations, which are coupled in only one direction. A single nonlinear equation results, which can be solved numerically very rapidly leading to a significant speed up for solving the original Rayleigh–Helmholtz equation and the ability to model faster acoustic propagation.

Accounting for water column variability in shallow-water waveguide characterizations based on modal eigenvalues

Kyle M. Becker
Penn State University/Appl. Research Lab., P.O. Box 30, State College, PA 16804 USA
Fax: 814-863-8783 kmbecker@psu.edu

The influence of water column variability on the characterization of shallow-water waveguides using modal eigenvalue information is considered. This work is based on the relationship between the acoustic pressure field in shallow water and the depth-dependent Green's function through the Hankel transform. In many practical situations, the Hankel transform can be approximated by a Fourier transform, in which case the Green's function is approximated by a horizontal wave number spectrum with discrete peaks corresponding with individual modal eigenvalues. In turn, the wave number data can be used in inverse algorithms to determine geoacoustic properties of the waveguide. Wave number spectra are estimated from measurements of a point source acoustic field on a horizontal aperture array in the water column. For range-dependent waveguides, techniques analogous to using a short-time Fourier transform are employed to estimate range-dependent wave number spectra. In this work, water column variability due to linear internal waves and mesoscale features are considered. It will be shown that these two types of variability impact the estimation of range-dependent modal eigenvalues in different ways. Approaches for accounting for these different types of variability will be discussed as they apply to waveguide characterization.

Geo-acoustic Doppler spectroscopy: a novel acoustic technique for surveying the seabed

Michael J. Buckingham
Marine Physical Laboratory, Scripps Institution of Oceanography, University of California, San Diego, La Jolla, CA, 92093-0238, USA

Many physical processes in the ocean may be investigated using sound rather than EM waves, since the latter are heavily attenuated in seawater. In particular, sound is commonly used to survey the seabed in connection with various offshore engineering projects, for example, cable laying and oil rig construction, and also, of course, numerous naval applications. Recently, a new acoustic technique, known as Geo-Acoustic Doppler Spectroscopy, has been developed for characterizing the seabed in shallow water. The technique is novel in that it utilizes a low-flying, propeller-driven light aircraft as an acoustic source. The propeller and the engine both produce sound and, since they are rotating sources, the acoustic signature from each takes the form of a sequence of narrow-

band harmonics. Although the coupling of the signal across the air–sea interface is inefficient, due to the large impedance mismatch, sufficient energy penetrates the surface to provide a workable underwater signal. Some of this energy reflects off the seabed, thus acquiring information about the sound speed in the sediment. An inversion of the acoustic signals detected at sensors either in the water column or buried in the sediment returns the geo-acoustic parameters of interest. Since the aircraft is a rapidly moving source, the received harmonics are significantly Doppler shifted. In essence, the magnitudes of these Doppler shifts provide a direct measure of the sound speed in the seabed, and once the sound speed has been determined the remaining parameters are estimated using strong correlations that are known to exist between them.

Scattering from finite cylindrical targets in a horizontally stratified waveguide

Zhengliang Cao, Shuanping Du, Shihong Zhou, Qianliu Cheng, and Fangyong Wang

Hangzhou Appl. Acoust. Res. Inst., Hangzhou 310012 China

The scattering of acoustic waves by submerged targets in a waveguide has attracted considerable interest from scientists over the past decades. As a benchmark, Ingenito's waveguide target scattering model [F. Ingenito, J. Acoust. Soc. Am. 82, 2051-2059 (1987)] is widely used to calculate the single scattering from simple objects in a horizontally stratified ocean waveguide. Based on the assumption that the plane wave scattering function of a finite cylinder is coupled with incident and scattered normal modes at the target center, the model is developed to calculate the acoustic field scattered by finite cylindrical targets in a horizontally stratified waveguide. It allows a simple physical interpretation for the directional character for cylinders with different material and structure, such as finite cylindrical shells with more complex scattering functions. Sample numerical calculations are given for two typical cases for the finite cylinder: variation of azimuthal angle on a horizontal plane and variation of elevational angle on a vertical plane. The results show an obvious difference between the two cases though the scattering function is the same. In addition, scattered fields by cylinders with different material and structure are analyzed in different azimuthal or elevational angles. [*Work supported by the National Natural Science Foundation of China (Grant No. 10704068).*]

Geoacoustic inversion in a spatially and temporally variable shallow water environment

Ross Chapman and Yong-min Jiang

School of Earth and Ocean Sciences, University of Victoria, Victoria, BC V8W 3P6

Matched field inversion for geoacoustic model parameters requires an accurate knowledge of the ocean environment for calculating replica acoustic fields. This paper reports results of matched field inversion of data from the Shallow Water 06 (SW06) experiment that was carried out in a shallow water environment in which the water column sound speed profile was spatially and temporally variable. The experimental site was near the edge of the New Jersey continental shelf where ocean water variability was observed due to internal waves and the shelf break front. The water column sound speed profile was characterized by a variable thermocline between relatively stable upper and lower homogeneous layers. The ocean bottom consisted of relatively fine grain silty-sand above a prominent sub-bottom interface at about 20 m below the sea floor. Multi-tone continuous wave data were obtained on a 16-element vertical line array that was deployed at a site where the water depth was approximately 80 m over a large area near the shelf break edge. The sound source transmitted the tones at fixed ranges of 1, 3 and 5 km for periods of about 5 minutes at each range. Eight tones from 53 to 700 Hz were used in a Bayesian matched field inversion to develop a geoacoustic model for the site. A simple geoacoustic model was estimated, consisting of a single sediment layer that was parameterized by the variation with depth of the sound speed, attenuation and density. The inversion accounted for the variable water column sound speed profile by parameterizing the profile using empirical orthogonal functions (EOFs), and including the EOFs as parameters in the inversion. Two approaches were used to obtain information about the sound speed variability. The first used only the variation in the thermocline, whereas the second used EOFs for the full water column. The inversions showed that consistent estimates of the geoacoustic model parameters could be obtained with either of the two approaches. However, the computation load was far less for the simple approach that modeled only the variation in the thermocline. The estimated model was characterized by an inhomogeneous sediment layer of about 20 m in which the sound speed decreased from about 1620 m/s at the sea floor, and a higher speed (~1750 m/s) sub-bottom layer. These values were consistent with ground truth results from in situ measurements and chirp sonar surveys carried out during the experiment. The inversion was not highly sensitive to attenuation at the closer ranges, but estimated a non-linear frequency dependent attenuation from the data at 5 km. [*Work supported by the Ocean Acoustics Team at Office of Naval Research.*]

Observation and modeling of acoustic signal intensity fluctuations in the northeastern South China Sea shallow waters

Ching Sang Chiu
Department of Oceanography, Naval Postgraduate School, Monterey, CA, USA

On the northeastern South China Sea (SCS) shelf and slope, large_amplitude, nonlinear internal waves with tidal and higher frequencies have been observed to produce the dominant variability in the water_column sound_speed field that, in turn, lead to large fluctuations in the intensities of the transmitted acoustic signals. The first of such simultaneous oceanographic and acoustic observations in the region was made during the Asian Seas International Acoustics Experiment (ASIAEX). The ASIAEX oceanographic data, aided with additional measurements and modeling analyses by oceanographers, show that these nonlinear internal waves originate from near the Luzon Strait, propagate through the deep basin, and can transform from depression to elevation waves on the shelf. Drawing upon the published results of Ramp et al. (2004), Chiu et al. (2004), Reeves (2008), and Yang et al. (2009), among others, the physical oceanographic characteristics of the SCS nonlinear internal waves are first summarized. Example observations of the vertical and temporal structure of the fluctuating acoustic signal intensity are then discussed, with the interpretation of the observed characteristics and statistics aided by a coupled_mode propagation model applying to realistic, coincident sound speed fields that were empirically derived. Finally, Reeves' (2008) extension of Dyer's (1970) theoretical model for intensity level statistics for the case of pulse transmission is discussed. The extended theory generally provides an upper bound for the observed variances, and as the time window in estimating the statistics lengthens, the observed variances converge to the theoretical ones.

Wave propagation in water-saturated sand and grain contact physics

Nicholas P. Chotiros
Applied Research Labs, The University of Texas at Austin, TX 78713-8029

Measurements in sandy ocean sediments over a broad range of frequencies show that the sound speed dispersion is significantly greater than that predicted by the Biot–Stoll model with constant coefficients, and the observed sound attenuation does not seem to follow a consistent power law. The sound speed dispersion may be explainable in terms of the Biot–Stoll plus complex frame bulk and shear moduli that are governed by the grain–grain contact physics. In the case of water-saturated sands, the contact stiffness is dominated by squirt flow and viscous drag of a thin fluid film that permeates the contact area. Using this approach, the observed sounds and shear speed and attenuations may be explained. [*Work supported by the Office of Naval Research, Ocean Acoustics Program*.]

Observations of 0^{th} order head waves in the Yellow Sea

Peter H. Dahl
Applied Physics Laboratory and Dept. of Mechanical Engineering, University of Washington, Seattle, Washington, USA
Jeewoong Choi
Ocean Acoustics Laboratory, Dept. of Environmental Marine Sciences, Hanyang University, Ansan, Korea

Measurements made as part of the 1996 Yellow Sea experiment at location 37° N, 124° E, undertaken by China and the U.S. are analyzed. Signals generated by explosive sources were received by a 60-m-length vertical line array deployed in waters 75 m deep. Evidence is presented that precursor arrivals measured at ranges less than 1 km are refracted waves that are zeroth order in their ray series classification, and this directly points to the existence of a gradient in sediment sound speed. In contrast, first-order head waves, which are much weaker in amplitude, would exist only if this gradient were absent. It is found that the energy spectrum of precursor arrivals agrees well with a zeroth-order model, i.e., it is proportional to the source amplitude spectrum, S(f), where f is frequency, rather than a first-order model, which would have it proportional to S(f)/ f. From travel time analysis the sediment sound speed just below the water–sediment interface is estimated to be 1573 m/ s with a gradient of 1.1 s-1, and from analysis of the energy spectrum of the precursor arrivals the sediment attenuation is estimated to be 0.08 dB/m/kHz over the frequency range 150–420 Hz. The results apply to a nominal sediment depth of 100 m.

Physical mechanisms underlying the generation of ambient noise by whitecaps

Grant Deane
Scripps Institution of Oceanography, UCSD, Code 0238
La Jolla, CA 92093-0238, email: gdeane@ucsd.edu

Bubble acoustics play a fundamental role in the generation of breaking wave noise in the open ocean. Bubble formation within a breaking wave is accompanied by a narrow-band pulse of sound with frequency inversely proportional to bubble radius. The superposition of these sound pulses form the Knudsen spectrum of ambient oceanic noise from a few hundred Hz up to tens of kHz and beyond. Two of the key physical processes underlying the amplitude and slope of the Knudsen spectrum are the bubble creation rate and the details of the fluid mechanical mechanism exciting the bubble sound pulse during bubble formation. Recent progress in understanding the role of bubble fragmentation within whitecaps in determining bubble creation rates and a detailed physical model for the bubble excitation mechanism will be discussed.

The effect of range dependence on the propagation of low frequency sound in shallow water over a limestone seabed

Alec J. Duncan[1] and Li Fan[2]
[1]*Centre for Marine Science and Technology, Curtin University of Technology, Perth, Western Australia*
[2]*Institute of Acoustics, Chinese Academy of Sciences, Beijing, China*

Acoustic propagation over limestone seabeds in shallow water is characterised by two quite different propagation regimes: at very low frequencies propagation is dominated by energy that travels through the seabed, whereas at higher frequencies propagation through the water column dominates. Previous work by the authors has shown that in the range-independent case, low-frequency propagation is dominated by a few discrete frequencies, which meet the condition that the seabed grazing angle of one of the modes corresponds to the seabed compressional wave critical angle. The purpose of this paper is to investigate the effect that range-dependent bathymetry has on this result using both modelling and measured data.

Dispersionless transform and signal enhancement application

Dazhi Gao+ and Ning Wang+ *
+ Department of Ocean Technology
** Department of Physics*
Ocean University of China, 238 Songling Rd. Qingdao, China

Shallow water acoustic waveguides are typically dispersive, i.e., a broadband signal spreads out in space and time as it propagates. This is a long-standing problem that constrains long-range propagation localization and underwater acoustic communication applications. A few years ago, a new transform was proposed in the community of ultrasonic Non-destructive Testing (NDT) that can be used to reduce the dispersive effect of propagating dispersive waves (IEEE TRANSACTIONS ON ULTRASONICS, FERROELECTRICS. AND FREQUENCY CONTROL, VOL. 50, NO. 4, APRIL 2003). Recently, one of the authors (Wang) has discussed this transform and its connection with the waveguide invariant in underwater acoustics (Ning Wang, “Dispersionless Transform and Potential Applications in Ocean Acoustics,” Presentation at the 9th WESPAC). The basic idea of the dispersionless transform is to use $\exp(ik(\omega)s)$ instead of $\exp(i\omega t)$ in the Fourier transform, which in fact is a modified Fourier transform taking dispersion into account. In this paper, we apply this method to signal enhancement in the application of long-range propagation. After the dispersionless transform, a broadband signal is enhanced significantly. The SNR can be enhanced 6 dB in simulation results and experiment data processing results, which shows the validity of this method. The potential applications of this method are in long-range propagation data preprocessing and underwater acoustic communication.

Adaptive bubble pulse cancellation and its applications

Fengxiang Ge, Yan Zhang, Zhenglin Li and Renhe Zhang
National Laboratory of Acoustics, Institute of Acoustics, Chinese Academy of Sciences, Beijing 100190, China, Email: gefx@mail.ioa.ac.cn

Explosive sources are widely used as sound sources in underwater acoustics experiments. Unfortunately, the resulting shock wave is often corrupted by bubble pulses, which results in undesired influences on observations and applications. Canceling these bubble pulses would greatly enhance the quality of observations and be helpful for applications. An adaptive filter, updated from an adaptive algorithm in the least squares sense for modeling the physical transmission from the explosive source to receiver, is proposed to cancel the bubble pulse. The auto-correlation functions of both the original field trial data and processed results show that the bubble pulses can be effectively cancelled. The normal modes of the propagated signal can be reconstructed from the processed results

with an adaptive time-frequency representation. The estimated time delay of the different normal modes is further applied in geo-acoustic inversion.

Signal recovery technique based on the physical method of underwater acoustics

Xin-Yi Guo, Guo-Qing Wu, and Li Ma
Institute of Acoustics, Chinese Academy of Sciences, Beijing 100190

In the underwater sound channel we often use an array to receive signals of distant sources. In practice, the received signals are often mixed with environmental interference. In the complex acoustic environment, the received signals are distorted greatly and elongated in time. In many practical applications, such as sound communications, sound remote sensing and active sonar signals, we hope to obtain the original waveform of the signals. From general theory, the received signals are the convolution of the emitted signals and the Green's function of the environment. In an environment with an unknown Green's function, simply relying on the array to record the information to determine the sound source signal wave propagation features and the environment is not enough. However, in certain circumstances, based on the physical method of underwater acoustics, the signal recovery can be successful. In this paper, based on signal recovery technology, and by modeling experiment results, we can recover signals that approximate the original waveform.

Study on geo-acoustics interface wave scattering characteristics

Xin-Yi Guo and Li Ma
Institute of Acoustics, Chinese Academy of Sciences, Beijing, 100190

This paper introduces the propagation and scattering characterizations of interface waves in an elastic half space. For a typical layer structure model, the propagating modes of an interface wave can be calculated, and the Green’s function can be obtained using the propagating modes. In a practical problem there may be buried objects in the medium. In this paper the interface wave scattering integral equation is derived, and the scattering interface wave field is simulated by computer. The convergence of the method has been proven to be very rapid by some practical examples, and the scattering strength can be obtained simultaneously. Sometimes, there are multiple buried objects in the medium; therefore, the interface wave scattering integral equation is applied to the calculation of the multiple-object scattering problem using the integral equation of the scattering elastic wave field associated with multi-inhomogeneities. In order to achieve the detection of buried objects using the interface wave, there is a need to verify the method. In this regard, the interface wave signal extraction, propagation velocity, propagation attenuation, and several other aspects are analyzed. The time difference between the direct and echo waves in the received signal can be obtained according to the geometric relationship of the buried objects, and the source and geophone array locations.

Geoacoustic inversion using towed line array and ship noise based on near-field MFP

Yonggang Guo, Zaixiao Gong, and Fenghua Li
National Laboratory of Acoustics, Institute of Acoustics, Chinese Academy of Sciences, Beijing 100080, China, Fax: 86-10-62565617, Email: gyg@mail.ioa.ac.cn

Geoacoustic inversion is one of the most important topics in ocean acoustics. In this paper, a method to invert seabed parameters using a towed line array with near field Matched-Field-Processing from the tow-ship noise is developed. A towed line-array system is easy to deploy and offers the possibility for estimating range-dependent seabed properties. Simulations and experimental results indicate that low (1 kHz) frequency noise can be used to estimate bottom velocity, sub-bottom layer structure and thickness. The line-array beamforming using the inverted seabed parameters is in good agreement with the experiment data. [*Work supported by National Natural Science Foundation 10734100*]

Studies of the characteristics of a densely-coupled array of underwater acoustic transmitting transducers

Zhengyao He and Yuanliang Ma
Institute of Acoustic Engineering, Northwestern Polytechnical University, Xi’an 710072, China

The characteristics of a densely-coupled array of underwater acoustic transmitting transducers are studied. At first, the electro-acoustic characteristics such as the admittance, the resonant frequency and the transmitting voltage response of the low

frequency barrel-stave flextensional transducer and a densely-coupled compact array composed of three identical transducers uniformly distributed on a circle with spacing much less than half a wavelength are measured by experiments. Then, the radiation impedances of a single transducer and transducers in the compact array are calculated by the boundary element model together with the finite element model. Based on the above results, the equivalent circuit model parameters of the transducer in different cases are calculated, which include a single transducer in air and in water, and the densely-coupled array of three transducers parallel connected in water. The characteristics of the transducers and array are analyzed by the equivalent circuit model obtained. The research results show that when the transducers make up a densely-coupled compact array, the resonant frequency decreases, and the transmitting bandwidth broadens. It is also shown that the mutual interactions among elements are significant for the compact array. The mutual radiation resistance between two transducers is close to the self-radiation resistance of the transducers. The vibration velocities of the transducers in the compact array are nearly 1/3 that of single transducer, and the radiation acoustic power and transmitting voltage response of the array are nearly the same as that of single transducer, when the driving voltages of the array and single transducer are kept unchanged. Furthermore, the transmitting source level of the 3-element compact array is 8.7 dB higher than that of a single transducer if the vibration velocities of the transducers in the array are the same as that of a single transducer. The proposed technique can be used to conduct the design of densely-coupled compact arrays of transmitting transducers. [*This work was supported by the National Natural Science Foundation of China (10734030), the China Postdoctoral Science Foundation funded project (20080431248), and the NPU Foundation for Fundamental Research (NPU-FFR-JC200805). Email address: hezhengyao@163.com.*]

Nonlinear internal wave behavior at south of Hai-nan Island and simulating their effect on acoustic propagation

Tao Hu, Li Ma, and Yunpeng Zhang
Institute of Acoustics, Chinese Academy of Sciences, Beijing 100190

An internal waves (IWs) observation experiment was fielded south of Hai-nan Island in July 2004. Three moored vertical arrays of thermistors were placed to estimate propagation direction and velocity of IWs. From the IW data, non-linear IWs were found. Non-linear IWs occurred at the time of flood tide at night. Computation indicates the velocity of the IWs was 0.54 m/s, and from the propagation direction of the IWs we estimate that the IWs may have come from the Xi-sha Islands. The dnoidal model of KdV (Korteweg–deVries) functions is used to simulate the waveform of non-linear IWs. The wave crest interval of non-linear IWs shortens with the propagation of IWs. Power spectra of high frequency linear IWs have a maximum at a similar period as that of the non-linear IWs. This implies that the trailing tail of the non-linear IWs affects the water between two non-linear IWs, and the waveform of the non-linear IWs' tail evolves from nonlinear to linear. We simulate the non-linear IWs' effect on acoustic mode coupling of sound propagation. We found, different from commonly believed, that non-linear IWs can also lead to a reduction in the transmission loss of sound.

Statistical estimation of source location in the presence of geoacoustic inversion uncertainty

Chen-Fen Huang
Institute of Oceanography, National Taiwan University, Taiwan

A statistical estimation of source location incorporating uncertainty in the ocean environmental model parameters is derived using a Bayesian approach. From the geoacoustic inversion procedure, a joint posterior probability distribution (PPD) of the environmental parameters that reflects uncertainty in the ocean environments is obtained. This geoacoustic inversion uncertainty is then mapped into uncertainty in the acoustic pressure field and is propagated through the Bartlett matched-field processor for source localization. Using a data set from the ASIAEX 2001 East China Sea experiment, the estimated source location and its variability over a time interval are compared with the measured source position.

Finite-element modeling in ocean acoustics: Where are we heading?

Finn B. Jensen[1] and Mario Zampolli[2]
[1]*NATO Undersea Research Centre, 19126 La Spezia, Italy – jensen@nurc.nato.int*
[2]*TNO, 2509 JG The Hague, The Netherlands – mario.zampolli@tno.nl*

The technique of choice for solving structurally and geometrically complex vibration problems is the finite element (FE) method. In ocean acoustics the use of FE methods remains a computational challenge even for low-frequency propagation problems because the computational domain (for a 2D geometry) is typically 10x1000 _ at 100 Hz. Localized scattering problems involving objects of a few 10s of acoustic wavelengths in dimension have recently received much attention from the research community, and this may be a class of problems better suited for the FE modeling approach. This talk

summarizes 10 years of NURC experience with the application of a state-of-the-art FE code [Zampolli *et al.*, JASA **122**, 1472–85 (2007)] to propagation and scattering problems in ocean acoustics. We show benchmark results for low-frequency propagation in a range-dependent waveguide with an elastic bottom, and object scattering results for spheres and cylinders placed near the sea floor. Despite the computational burden associated with the FE method, its generality in treating propagation in layered fluid/elastic media of complex geometry without theoretical approximations makes it very attractive for acoustic benchmarking. And, as experience shows, what is computationally impractical today, will be easily done on a desktop computer 10 years from now.

An improved passive phase conjugation array communication algorithm

Ning Jia, Zhongyuan Guo, Jianchun Huang and Geng Chen
Institute of Acoustics, Chinese Academy of Sciences, Beijing 100190, China

The time-varying, dispersive, multipath underwater acoustic channel is a challenging environment for reliable coherent communications. A method proposed recently to cope with intersymbol interference (ISI) is Passive-Phase-Conjugation (PPC) combined with Decision-Feedback Equalization (DFE). Based on the theory of signal propagation in a wavguide, PPC can mitigate channel fading and produce a high signal-to-noise ratio (SNR) using a receiver array. Residual ISI is removed by DFE. This method will lead to explosive divergence when the channel has rapid spatial variation because of an inaccurate channel estimation contained in PPC. We propose an improved algorithm in this paper to estimate and supervise the channel between all the communication processes; as a result, the change of channel can be found in time and we redo the PPC using the new channel estimation. Using simulated and at-sea data, we demonstrate that this algorithm can improve the stability of the original algorithm in a rapidly changing channel.

Estimating marine sediment properties in a temporal varying water column environment

Yong-Min Jiang and Ross Chapman
School of Earth and Ocean Sciences, Univ. of Victoria
Victoria, BC V8W 3P6, Canada, minj@uvic.ca

This paper presents geoacoustic inversion of broadband data collected at a site on the New Jersey continental shelf in the Shallow Water 2006 experiments. Multiple source depths, vertical line array and the short distance between the source and receiver were used to obtain a wide-angle coverage of the sea bottom reflection. The sound speed profile in the water was a typical coastal one that had a strong thermocline in the middle part of the water column. During the data collection, the variability of the water column sound speed was evident. To mitigate the effect of the variable water environment on the geoacoustic inversion, a three-step inversion was carried out. The geometric parameters such as the water depth, source and receiver range were inverted first, then the water column sound speed profile was determined by inverting the coefficients of its empirical orthogonal function representations, and finally the sediment sound speed and layer thickness were inverted by using the parameters estimated in the first two steps. In addition, a method of estimating the sediment attenuation and its frequency dependence by using this short-range experimental geometry is developed. To examine the validity of the low frequency attenuation measurement method, the uncertainty of the attenuation is analyzed by combining the errors from measurement, and the uncertainties of the auxiliary parameters such as the sediment sound speed and layer thickness estimates obtained from Bayesian geoacoustic inversion. [*Work supported by ONR Ocean Acoustics.*]

Theory and modeling horizontal refraction in shallow water

Boris Katsnelson
Voronezh State University, 1 Universitetskaya Sq., Voronezh, 394006, Russia
e-mai: katz@phys.vsu.ru
Mohsen Badiey
University of Delaware, USA

Horizontal refraction of sound signals is a well known 3D phenomenon, caused by the existence of different anisotropic structures (nonlinear internal waves, coastlines, and temperature fronts) in the ocean and especially in shallow water regions. Horizontal refraction can lead to redistribution of the sound field in the horizontal plane and can be manifested as spatial or temporal fluctuations of different parameters of the sound field at the receiving array (single hydrophone, vertical or horizontal array). In this talk the

concepts and methods describing horizontal refraction of sound waves in shallow water, and the physical phenomena taking place due to horizontal refraction are presented. Theoretical analysis and modeling are carried out using the method of vertical waveguide modes and horizontal rays and the method of vertical modes and the parabolic equation (PE) in the horizontal plane. The models of spatial and temporal fluctuations of intensity and their frequency dependence, and dependence on mode number for different shallow water waveguides are presented. Analytical and numerical results for the scintillation index (SI) of the sound field in the presence of factors initiating horizontal refraction (for example internal waves) obtained by the authors are discussed.

The nature of sound propagation on the New Jersey continental shelf: Analysis of acoustic measurements taken during SW06

David P. Knobles
Applied Research Labs,_University of Texas at Austin,_P.O. Box 8029, Austin, TX 78713-8029

A comprehensive set of acoustic and environmental measurements were made in August–September 2006 on the New Jersey continental shelf. Physical measurements included the sound speed profile on various spatial and temporal scales and chirp seismic reflection profiles of the seabed. Acoustic measurements included recordings on L-shaped arrays from tows of continuous wave sources, from impulses emitted by combustive sources, and from the sound generated by a tropical storm. The sound speed structure of the seabed was derived from inversion analyses of these signals. The frequency dependence of the seabed attenuation was inferred from analyses of measured transmission loss as a function of range over the 50–3000-Hz band. A propagation model incorporating this information permits an interpretation of the range-depth dependence of sound propagation from both continuous wave and impulsive broadband sources. Further, it can be demonstrated that the observed frequency dependence in the 50–3000-Hz band of the received signals from a tropical storm band is consistent with a non-linear frequency dependence of the attenuation of sound in the seabed.

Joint coherent time-reversal processing and incoherent diversity for distributed target detection in shallow water

ChunXiao Li[1,2] and XianYi Gong[2,3]
[1] Zhijiang College of Zhejiang University of Technology, Hangzhou 310024, China
[2] Department of Information Science and Electronic Engineering, Zhejiang University, Hangzhou 310027, China
[3] Hangzhou Applied Acoustics Research, Hangzhou 310012, China

Due to multi-path propagation in shallow water, the resolution of time-reversal processing is much higher than that obtained with the same time-reversal mirror in free space. Based on the characteristics of wave propagation in shallow water, a target cannot be treated as a point-like scatterer even when its actual dimension is not too large. Considering that its dimension is larger than the corresponding dimension of the resolution of time reversal, it can be modeled as a distributed target with many small elemental scatterers. Moreover, if the amount of energy reflected from the target toward the receiver is a function of the target aspect with respect to the transmitter/receiver pair, there will be degradation of detection performance. In this paper, the idea of focusing on multiple spots on the target to improve the detection performance is investigated. The signal processing method consists of both coherent time-reversal processing and incoherent accumulation of the output of time-reversal processing from each elemental scatterer. A waveguide experiment was carried out using a rigid 32-element source-receiver array in the 10–14-kHz frequency band with a target whose dimension is smaller than that of the resolution in free space but larger than that of the resolution in shallow water. The influence of target scintillations on detection using only coherent processing is evaluated. The effectiveness of incoherent processing that takes advantage of spatial diversity to improve detection performance is also evaluated.

Sonar detection range index estimation approach in uncertain environments

Fan Li, Sheng-ming Guo, and Yao-ming Chen
Institute of Acoustics, Chinese Academy of Sciences, Beijing, China 100190

The traditional detection range index prediction of sonar systems assumes a deterministic environment and causes overestimation of the detection range index. The realistic ocean environment consists of a quantitative measure of environmental uncertainty, such as sound speed profile, sea depth, and so on. An estimation approach that incorporates the effects of environmental uncertainty into the sonar detection range index is proposed in this paper. The sonar detection range index prediction has been implemented using Monte Carlo simulations. In simulations the sound speed gradient, sea depth and bottom geo-

acoustic parameters, known to be important uncertainty environmental parameters, are generalized to stochastic variables and satisfy the normal distribution. The sonar detection range index with an unknown source depth is also considered.

Analysis of sound fields recorded with vector sensors

Fenghua Li, Mei Sun, and Renhe Zhang
National Laboratory of Acoustics, Institute of Acoustics, Chinese Academy of Sciences, Beijing 100080, China, Fax: 86-10-62565617, Email: lfh@mail.ioa.ac.cn

From data collected with vector sensors at several sites, the transmission losses of the particle velocities and pressures are examined. In particular, the components of the particle velocity fields both normal and tangential to the horizontal are studied. Theoretical and experimental results show that both vertical and horizontal particle velocity can be regarded as the summation of normal modes. The lower modes dominate for the horizontal particle velocity, while higher modes are relatively important for the vertical particle velocity. The intensity of the vertical particle velocity decreases faster than that of the horizontal particle velocity. The experimental results also show that the same modes of the horizontal particle velocity and the vertical particle velocity have similar losses, but different amplitudes and phases. Theoretical analyses indicate that the difference of the mode amplitudes between horizontal particle velocity and vertical particle velocity is dependent on the eigenvalue and receiver depths, which can provide information on the estimation of bottom parameters. Two geo-acoustic inversion schemes employing vector sensors have been developed. The first inversion scheme uses a combination of matched field processing and the difference of transmission losses between pressure and particle velocity. The second estimates the bottom sound speed and attenuation from the amplitudes of normal modes of particle velocities. Both methods can decrease the uncertainty of inversion in comparison with using hydrophones. [*Work supported by National Natural Science Foundation 10734100.*]

Sound horizontal correlation and its effect on beamforming

Fenghua Li and Renhe Zhang
National Laboratory of Acoustics, Institute of Acoustics, Chinese Academy of Sciences, Beijing 100080, China
Fax: 86-10-62565617, Email: lfh@mail.ioa.ac.cn

A shallow water experiment was performed recently. One of the primary objectives of this experiment was to investigate the effects of the ocean environment on the horizontal correlation of sound. A 500-m-long horizontal line array with 32 elements was deployed on the bottom to record signals transmitted from explosive sources in different directions at different ranges. It was observed in the experiment that the longitudinal correlation of low frequency signals has an oscillatory structure, and the longitudinal correlation length in units of wavelengths increases with increasing frequency. A model has been proposed to explain the observations. The theoretical analysis and numerical simulations indicate that the non-linear frequency relationship of the bottom attenuation is the main cause of the observed frequency dependence of the longitudinal correlation length. The effect on beam forming of the degrading of the longitudinal correlation also has been investigated.
[*Work supported by National Natural Science Foundation 10734100.*]

Inversion of ocean environmental variations via time reversal acoustics

Jianlong Li, Wen Xu*, and Liling Jin
Department of Information Science and Electronic Engineering, Zhejiang University, Hangzhou 310027, China
Email: wxu@zju.edu.cn

Time reversal (TR) processing is derived from the invariance of the wave equation for a lossless medium to the change in the sign of the time variable. By retransmitting the TR version of the time-dispersed received signal propagated from a probe source (PS) to a source-receiver array, one can reacquire the transmitted pulse at the PS location (time compression and spatial focusing) when the waveguide environment is time invariant. However, if some environmental variations occur between the two transmissions, the retro-focusing signal will be defocused. This paper presents a novel method of environmental variation inversion by comparing the difference of the focused signals measured at the PS location with environmental perturbations between the two retransmissions. Because the sound speed profile (SSP) plays a critical role in an uncertain ocean environment, inversion of the SSP represented in terms of the empirical orthogonal functions is developed and discussed in detail. Examples of the method

applied to synthetic data are provided to demonstrate the method's feasibility. The advantages of this inversion method are (i) great signal-to-noise ratios can be obtained at the PS location so that the inversion error can be decreased, and (ii) variations of the environment at different times can be directly inverted by repeatedly retransmitting either the same received signal generated by one PS transmission or the updated received signals generated by updated PS transmissions.

Coherent reverberation model based on adiabatic normal modes in a range-dependent shallow water environment

Zhenglin Li[1, 2] Renhe Zhang[1] and Fenghua Li[1]

[1] *National Laboratory of Acoustics, Institute of Acoustics, Chinese Academy of Sciences, Beijing 100190, China, Fax: 86-10-62565617, Email: lzhl@mail.iao.ac.cn*

[2] *Haikou Laboratory of Acoustics, Institute of Acoustics, Chinese Academy of Sciences, Haikou 570105*

Ocean reverberation in shallow water is often the predominant background interference in active sonar applications. It is still an open problem in underwater acoustics. In recent years, an oscillation phenomenon of the reverberation intensity, which is due to the interference of the normal modes, has been observed in many experiments. A coherent reverberation theory has been developed and used to explain this oscillation phenomenon [F. Li et al., An oscillation of reverberation in the shallow water with a thermocline, Journal of Sound and Vibration, 252(3), 457-468, 2002]. But, the published coherent reverberation theory is for a range-independent environment. Following a derivation by F. Li and Ellis [see D. D. Ellis, A shallow-water normal-mode reverberation model, J. Acoust. Soc. Am., 97(5), 2804-2814, 1995], a general reverberation model based on adiabatic normal modes in a range-dependent shallow water environment is presented. From which, the coherent or incoherent reverberation field, as well as the reverberation intensity or reverberation vertical correlation, caused by sediment inhomogeneities and surface roughness, can be predicted. Observations of reverberation from the 2001 Asian Sea International Acoustic Experiment (ASIAEX) in the East China Sea are used to test the model. The model/data comparison shows that the coherent reverberation model can predict the experimental oscillation phenomenon of reverberation intensity and vertical correlation very well. [*Work supported by the Knowledge Innovation Program of the Chinese Academy of Sciences, Grant No. KZCX1-YW-12-2 and the National Natural Science Foundation of China under Grant No. 10734100*.]

Geo-acoustic inversion using shallow water ambient noise and analysis of uncertainty

Jianheng Lin, Baoyou Yin, and Xuejuan Yi

Qingdao Laboratory, Institute of Acoustics, Chinese Academy of Sciences, Qingdao 266023

Ambient noise in shallow water undergoes multiple reflections between the sea surface and seabed, thus, the spatial structure of the ambient noise field depends strongly on geo-acoustic characteristics of the seabed. A great deal of measurements show that the noise vertical coherence is a stable feature, changing little with sea states, which reflects the invariance of seabed parameters. Therefore, the noise vertical coherence can be used to invert for geo-acoustic parameters. In this paper, geo-acoustic parameters are estimated by the measured ambient noise coherence. Differential evolution is applied in the global optimization parameters search. However, geo-acoustic inversion is a strongly nonlinear process, so the inverted solution may be uncertain and non-unique. According to Bayesian theory, the solution is fully characterized by its posterior probability density (PPD), which combines prior information about the forward model with information from measured data. A fast Gibbs sampler (FGS) approach is used to calculate the multi-dimensional integrals of the PPD in the paper, and the validity of the inversion method based on ambient noise vertical coherence is checked. For these inversions two different seabed models were employed. First, the seabed is assumed to be a homogeneous fluid half-space. Another inversion procedure was also given using the second seabed model comprising a single homogeneous fluid sediment layer on top of a homogeneous fluid half-space. In the end, substituting these inversion results into the forward model, comparisons were made with shallow water noise data to estimate the uncertainties of seabed geo-acoustic parameters from broadband vertical coherence.

Effect of the tidal internal wave field on shallow water acoustic propagation

Ju Lin, Huan Wang, and Junping Sun

College of Information Science and Technology, Ocean University of China, Qingdao 266100, P.R. China

Internal waves (IW) are one of the most pronounced oceanic phenomena to the oceanographer. During past decades much effort has been made to investigate the effect of internal waves on shallow water acoustic propagation. Even though many field observations, such as SWARM95, have provided fruitful information on the relation between internal waves and acoustic propagation, it is useful to conduct more numerical simulations due to their feasibility. In this study, the shallow water internal wave environment is constructed by using a non-hydrostatic ocean model; the open boundary forcing is set by considering single or combined internal wave modes at the M2 tidal frequency. The topographic and initial oceanographic fields were obtained from the observations of AEYSFI 2005. In order to show the mode coupling caused by the internal wave field more clearly, the acoustic starting field using different single normal modes was adopted. The acoustic simulation can be used to check whether a specific combination of internal wave modes is related to the mode coupling, and which mode pair will be affected. The combination of internal wave modes can be separated into several groups, and even though the internal wave fields are different in each group for every case, the acoustic field structure and the mode coupling are similar. Different acoustic normal mode coupling occurred due to the different combination of internal wave mode forcing. When the parameters of the internal wave modes are modified gently, the acoustic mode coupling becomes quite different. It is interesting and important to investigate the sensitivity of acoustic field to the variability of the internal mode combination. [*This work is supported by the National High Technology Research and Development Program of China (Grant No. 2006AA09Z114), the Ministry of Science and Technology of China (National Key Program for Developing Basic Science Grant No. 2007CB411803), and The Scientific Research Foundation for the Returned Overseas Chinese Scholars, State Education Ministry of China (Acoustic Monitoring Technology of Shallow Water Dynamic Environment).*]

Inversion of bottom properties based on ship-radiated noise received by a towed horizontal array

Fuchen Liu and Shihong Zhou
Hangzhou Applied Acoustic Research Institute, Hangzhou City, 310012, China

This paper describes a method of ocean bottom properties inversion through matched field inversion (MFI) of shallow water acoustic data. The line-spectrum of ship-radiated noise received by a towed horizontal array is considered. In MFI, measured acoustic fields are compared with near-field acoustic fields calculated by a propagation model for many sets of parameter combinations by wavenumber integral theory. A genetic algorithm was used for solving this optimization problem. Sea experimental data analyses verify the performance. The estimated values of compressional wave speed and density were in good agreement with ground truth values from sediment cores. The shear wave speed and attenuation parameter appear to be sensitive parameters. As a cross check, range and water depth were also included as inversion parameters, and the inversion results were close to the known values within small uncertainties.

Uncertainty analysis of transmission loss in a very shallow water environment in the SiTzi-Wan Marine Test Field

Jin-Yuan Liu and Shih-Feng Yang
Institute of Applied Marine Physics and Undersea Technology, National Sun Yat-sen University, Taiwan
Chen-Fen Huang
Institute of Oceanography, National Taiwan University, Taiwan

Wide-band frequency sound propagation features and bottom sediment properties in a very shallow water environment were studied in the transmission loss experiments conducted in the SiTzi-Wan Marine Test Field (MTF) located at the Tzoin-Kaohsiung marine area. Acoustic transmissions were made from a UW-350 source deployed from the R/V *Ocean Researcher III* at a 10 m water depth, transmitting CW signals at 350, 800 and 1250 Hz, which were received on two ITC-6050c hydrophones towed by a drifting boat. A complete survey of the marine environment was carried out, including seafloor topography, morphology, subbottom profiles, currents, waves, and wind fields. Comparisons of the measured transmission loss (TL) and the predicted TL with its uncertainty are made for various environmental uncertainties estimated from the in situ measurements. Preliminary results show that sediment parameters render more uncertainties due to the less accurate measurements, as expected.

Forward coupling of normal modes in ocean acoustic tomography

Jinzhong Liu
The First Institute of Oceanography, 266061 Department of Physics, Weifang University, 261061
Ning Wang and Dazhi Gao
Department of Physics, Ocean University of China, Qingdao, 266071

Ocean acoustic waveguides are often range-dependent and there may exist acoustic mode coupling phenomena induced by fluctuations of the sound speed profile in the sound propagation path. The time-domain coupled mode signals can be separated from the received acoustic signals because of the group speed differences of acoustic modes in acoustic pulse propagation. Information on the variation of the ocean interior in the range direction is contained in the time-domain acoustic coupled mode signals: the arrival time of the acoustic coupled mode signal is related to the position of variations of the ocean interior and the amplitude (or pattern) of the acoustic coupled mode signal is related to the intensity (or the space distribution) of variations of the ocean interior. Based on this

we introduce forward coupling normal mode ocean acoustic tomography, which was used to monitor ocean front variations in AEYFI05 (Acoustics Experiment of Yellow sea Oceanic Front and Internal Waves 2005).

Sound velocity fluctuation due to linear internal waves in the northern Yellow Sea

Kun Liu and Shihong Zhou

Hangzhou Applied Acoustic Research Institute, Hangzhou City, 310012, China

Data measured by a thermal chain array, which covered a depth range of 4–46.6 m in the northern Yellow Sea in September 2008, are analyzed in this paper. The result shows that the water particle vertical displacement of 5–19 m occurs due to internal waves. The internal waves are dominated by the low modes. The vertical displacement power spectrum of isotherm curves was obtained and the spectrum attenuation coefficients are between –1.93 and –2.19. The mean spectrum attenuation coefficient is –2.05, which is consistent with the G–M internal wave spectrum with power law of –2. With these values, the magnitude of the sound velocity fluctuation $\delta c/c$ caused by internal waves is predicted in different ranges, depths and times, respectively. The result shows that the mean $\delta c/c$ is about and varies strongly at the depth of the 20–30-m thermocline layer. The results will be useful for deterministic modeling and stochastic modeling in a random ocean.

Low frequency volume reverberation measurements in turbid seawater

Yongwei Liu, Qi Li, Dejiang Shang, Chao Zhang, Rui Tang, Dajing Shang, and Mengying Chen

Shallow coastal waters are characterized by high levels of suspended sediment particles relative to the open ocean. This kind of seawater is also characterized as turbid seawater. Devices operating in these environments, such as naval mine-hunting sonars, side-scan surveying sonars, and acoustic Doppler current profilers typically employ frequencies ranging from tens of kHz to several hundred kHz, with propagation paths up to several hundred meters. At these frequencies and ranges, the additional sound absorption arising from viscous absorption and scattering by suspended sediment particles leads to significant sound attenuation.

An experimental investigation on volume reverberation has been done in the sea area outside Yangtze River Estuary, where the seawater contains a lot of suspended sediment particles. The scattering data at 9 sites in the frequency range 10 to 40 kHz, in steps of 1 kHz, has been obtained. The results demonstrate that volume scattering coefficient values in turbid seawater may be expected to fall in the range –60 to –100 dB re m^{-1}. Simple theory indicates that volume reverberation intensity is directly proportional to the sound source intensity and to the pulse length. However, because sound absorption caused by suspended sediment particles in turbid seawater is much larger than that in clear seawater, the volume reverberation intensity does not change with the pulse length of the transmitted signal, even when the pulse length is less than 0.5 ms. Temperature, salinity, and content of oxygen in the seawater has little effect on volume reverberation intensity. But suspended sediment particles may have a great effect on volume reverberation intensity. If the concentration of suspended sediment particles changes from 31 mg/L to 47 mg/L, the volume reverberation intensity may be changed by 30 dB.

It is concluded that the results in the paper are also appropriate for estimating volume reverberation in natural coastal waters with suspended sediment particles, such as the Yellow Sea, the East China Sea offshore of the Yangtze and Yellow rivers, Persian Gulf, the South Atlantic offshore of the Amazon River, Bristol Channel, and so on.

Underwater time service and synchronization based on time reversal techniques

Hao Lu[1,2], Hai-bin Wang[1], Abdeldjalil Aissa el Bey[3], and Ramesh Pyndiah[3]

[1] National Laboratory of Acoustics, Institute of Acoustics, Chinese Academy of Sciences, Beijing 100190, China; Email: whb@mail.ioa.ac.cn
[2] Graduate University of Chinese Academy of Sciences, Beijing 10019, China;
[3] Technopôle Brest Iroise, CS 83818, 29238 Brest cedex 3, France

Real time service and synchronization are very important to many underwater systems. Time synchronization is important for data effectiveness. Especially in underwater navigation and positioning systems, time synchronization is one of the critical factors for positioning accuracy. Right now, there are many available time service and synchronization systems, such as Global Navigation Satellite System (GNSS) and other specially designed systems. These systems generally use electromagnetic waves for time dissemination. But because of the multi-path propagation and random phase fluctuation of acoustic signals in the ocean, conventional radio time service does not work well underwater.

In order to reduce the multi-path contamination and increase the accuracy of time service, the Time Reversal Mirror (TRM) technique is effectively utilized in this paper. On this basis, a new method is presented which is called Time Reversal Mirror Real Time service and synchronization (TRMRT). In this method, the client sends a time service signal to the server; then the received signal at the server side is time-reversed and retransmitted back to the client. From a detailed analysis, it can be found clearly that the retransmitting time is just half of the time for the whole time service task. The principle of this method is analyzed in detail. Then the performance and some properties of it are simulated and discussed. From the analysis, it can be found clearly that TRMRT can bypass the processing of multi-path at the server side; and the multi-path contamination at the client side is greatly reduced by TRM. Therefore, this method can improve the accuracy of the time service. Furthermore, the complexity of the system is obviously decreased. As an efficient and precise method of time service, TRMRT could be widely used in underwater exploration activities and underwater navigation and positioning systems.

Matched-field geoacoustic inversion by inverting ship-noise data

Licheng Lu and Li Ma
Key Laboratory of Underwater Acoustic Environment, Institute of Acoustics, Chinese Academy of Sciences, Beijing, 100190

Geoacoustic inversion results by inverting ship noise data obtained with a vertical array during the East Sea Experiment in April 2006 are reported. The inversion process uses hybrid optimization and Bayesian inversion techniques based on matched-field processing to explore the seabed parameters, such as velocity, density, and attenuation. The hybrid optimization, which combines global simulated annealing and downhill simplex, is used to interrogate geoacoustic parameters from multiple data segments as the ship navigated around the vertical array. Bayesian inversion quantifies the uncertainty of geoacoustic parameters using the Gibbs Sample (GS) approach to estimate the posterior probability density (PPD). An isotropic sediment overlying an infinite basement is the geoacoustic model assumed, and ship noise tones near 100 Hz and 405 Hz are used in the inversion. Sediment velocity and thickness are well determined, as is the basement velocity. The density and attenuation are not determined well, mostly because the sound interacted little with the seabed for short transmission distances. Ship noise transmission loss is compared with modeled results at 100 Hz, 405 Hz, and 695 Hz.

Acoustic ducting, refraction, and shadowing by curved (funky) internal waves in shallow water

James Lynch, Y.T. Lin, Tim Duda, Art Newhall, and Glen Gawarkiewicz
Applied Ocean Physics and Engineering, Woods Hole Oceanographic Institution, Bigelow 209, MS#12, Woods Hole, MA 02543

In this presentation, we will discuss acoustic ducting, refraction, and shadowing by curved internal waves in shallow water. The emphasis on curved waves differs from the idealized straight line waves that have been studied previously. Funky just denotes different and interesting. By using the Weinberg–Burridge theory of vertical modes and horizontal rays, we can produce an acoustic 2-D analogue of classical geometrical optics to describe propagation in the horizontal x–y plane. Using this analogy, we see that just like light, sound can be 1) trapped in the ocean analogue of a light pipe, 2) bent dispersively by internal waves like light is bent by a lens or a prism, and 3) shadowed by oceanographic objects such as internal waves. These effects are in the x–y plane, so this theory describes a fully 3-D acoustic propagation effect. Theory, computer simulations, and data from the Shallow Water 2006 (SW06) experiment will be used to examine these phenomena in detail. Directions for future research in this area will also be discussed.

Geoacoustic measurements and tomographic inversions in the East China Sea and on the New Jersey Shelf

James H. Miller and Gopu R. Potty
Department of Ocean Engineering, University of Rhode Island, Narragansett, RI 02882 USA

During the Asian Seas International Acoustics Experiment (ASIAEX), sediment tomography measurements were conducted in the East China Sea in approximately 100 m of water [Miller et al., IEEE J. Ocean. Eng. 29 (4), 940-951 (2004)]. A series of wideband sources (each 38 g of explosive) were detonated at a depth of 50 m in a circular pattern of radius 30 km. A 14-element vertical hydrophone array was deployed off the R/V *Melville* at the center of the circle. The acoustic data collected by the vertical array were processed to calculate the mode arrival times as a function of frequency. These arrival times were then used in our tomography technique to invert for sediment geoacoustic properties, specifically compressional sound speed and attenuation. Gravity and piston cores, chirp and watergun seismic profiling, and historic sediment maps were compared with the tomographic inversions. Compressional sound speed was estimated in the cores with a technique based on Biot theory, and density and porosity profiles. The historic data showed a surficial sediment front between a mud-and-sand mixture and a

sandy sediment. The surficial sediments in the experimental area vary in compressional sound speed from a low of 1600 m/s in the northwest corner to 1660 m/s in the southeast corner. This spatial variation was also observed in the tomography inversions. The chirp and water-gun measurements indicate that the sub-bottom structure consists of a thin (< few meters) veneer of sediment of variable thickness directly beneath the seafloor. Beneath this veneer there is an extensive package of sediment with relatively uniform acoustic attributes. Three channels dissect this unit. Channel fill consists of sediment that produces an extremely heterogeneous distribution of acoustic attributes. In the Shallow Water 06 Experiment on the New Jersey Shelf, estimates of sediment compressional wave speed and attenuation were made [Potty et al., J. Acoust. Soc. Am., EL146, 124(3), September 2008] using acoustic normal modes produced by a combustion sound source [Wilson et al., J. Acoust. Soc. Am. 97(5), 3298, May 1995] deployed by the University of Texas Applied Research Laboratory off the R/V *Knorr.* The estimates are presented and compared to those in the East China Sea and in other regions of the world. [*Work supported by ONR*.]

Single-mode close-loop excitation in shallow water using two vertical hydrophone arrays

Dayong Peng, Tianfu Gao, Juan Zeng, Haijun Liu, Haifeng Li, and Wenyao Zhao

Institute of Acoustics, The Chinese Academy of Sciences, Beijing 100190

An algorithm for single-mode close-loop excitation in shallow water using two vertical hydrophone arrays is presented. Single-mode excitation is a powerful tool for studying a great variety of oceanographic processes. The desired single-mode sound field is the only variable that needs to be given in single-mode close-loop excitation. In order to get the exact desired single-mode sound field, two vertical hydrophone arrays are used to determine the correct vertical wave number. By analyzing the covariance of the estimated value of the Green's function matrix, an optimal source array weight matrix is presented for estimating the Green's function matrix. An algorithm based on the weight matrix makes single-mode excitation converge at maximum speed and be stable. Advantages of the algorithm are confirmed by numerical simulations. Results of an experiment performed in a coastal environment are presented.

The effects of a sloping bottom on the vertical correlation

Zhaohui Peng, Lujun Wang, and Zhenglin Li

National Laboratory of Acoustics, Institute of Acoustics, Chinese Academy of Sciences, Beijing 100190, Email: pzh@mail.ioa.ac.cn

The sound field vertical correlation is essential for the aperture selection of vertical arrays used for matched field processing, but has not received much attention in the ocean acoustics community. The sound field vertical correlation as functions of vertical spans and ranges were studied by numerical simulations and experimental data analysis. The experiment was conducted in the continental shelf break in the South China Sea. Wideband explosive sources were deployed either at 7 m or at 100 m along three radial tracks with slope angle varying from 0 to 0.45 degree. Signals were received by a vertical line array with elements spanning 18 m to 61 m and recorded by a 32-channel digital recorder. The coupled mode theory and the wedge mode theory are used to explain the numerical and experimental results. It is shown that there is a larger difference in the sound field vertical correlation between the upsloping sea bottom and the downsloping sea bottom due to normal mode coupling excited by the sloping sea bottom. An oscillating phenomenon of the vertical correlation produced by the interference between normal modes is observed. [*The work was supported by the National Natural Science Foundation of China under grant number 10523002*.]

Investigation of interference phenomena of broadband vector acoustic signals in shallow water

Shengchun Piao and Qunyan Ren

College of Underwater Acoustic Engineering, Harbin Engineering University, Harbin 15000, China

Although the ocean environment in shallow water is very complex, there still exists a stable interference pattern for broadband low frequency sound propagation. The waveguide invariant concept is introduced to describe the broadband interference structure of the acoustic pressure field in a waveguide, and now it is widely used in underwater acoustic signal processing. Acoustic vector sensors can measure the particle velocity in the ocean and provide more information on the underwater sound field. In this paper, the interference phenomena of broadband vector acoustic signals in shallow water are investigated by numerical simulation. Energy spatial-frequency distributions are shown for the energy flux density vector obtained by a combination of pressure and particle velocity signals, and they are analyzed according to normal mode theory. Comparisons of the interference structure between the scalar acoustic field and vector

acoustic field also have been made. The waveguide invariant concept is extended to describe the interference structure of the vector acoustic field in shallow water. A method for extraction of the waveguide invariant from interference patterns in vector acoustic field spectrograms is presented, which can be used in matched-field processing and geoacoustic inversion. It is shown that this method may have more advantages than the traditional methods, which calculate the waveguide invariant using measured sound pressure in the ocean.

Gaussian beam tracing for ocean acoustics

Michael B. Porter
Heat, Light, and Sound Research, Inc., La Jolla, CA USA

Gaussian bean tracing methods have emerged as a standard approach for modeling sound propagation in the ocean. The first implementations were developed in the 1970's by Bucker and evolved significantly. Today there are actually some four different types of Gaussian beam algorithms. They are quite different in terms of both the beam characteristics and their performance. This talk will review the development of the methods and their application to typical ocean acoustic problems.

The effects of source-receiver range and sound speed STD on the acoustic correlation time in the South China Sea

Yun Ren[1, 2] and Lixin Wu[1]
[1]*National Laboratory of Acoustics, Institute of Acoustics, Chinese Academy of Sciences, Beijing 100190, China, Email: renyun05@mails.gucas.ac.cn.*
[2]*Graduate University, Chinese Academy of Sciences, Beijing 100190, China*

An acoustic experiment was conducted in the South China Sea in 2009. Based on the ocean environment measurements in the experiment, the temporal coherence of sound transmission with the presence of internal waves is simulated by using a two-dimensional advective frozen-ocean acoustic propagation model. In deep water, coherence-time can be expressed as a function of the source-receiver range and the sound speed standard deviation (STD). It is supposed that the same function exists in shallow water. The experiential relationship of the coherence-time with the range and STD is fitted from the simulations, and compared with the results of the Asia Seas International Acoustics Experiment (ASIAEX2001). It is shown that the range dependence agrees with the deep water theory, but the sound speed STD dependence is different from the results of deep water and ASIAEX2001.

Target detection by receiving-transmitting-united MVDR TRBF under environmental mismatch

Yidi Ruan[1] and Xianyi Gong[2]
[1] *China Mobile Communications Corporation Zhejiang Company Limited, Hangzhou 310006*
[2] *Department of Information Science and Electronic Engineering, Zhejiang University, Hangzhou 310027*

Target detection and localization in a shallow water waveguide profoundly involves both acoustic propagation physics and sonar signal processing, and has been a topic quite important in theoretical and practical research. In recent years, the time reversal (TR) approach has been intensively investigated, not only as a physical process, but also as a signal processing method. In this paper, target detection and localization in an uncertain environment by TR processing is studied. We first fit TR into the framework of signal processing; then considering that the performance of TR spatial-temporal focusing is limited by the environment uncertainties, we come up with a new concept of transmitting-receiving-united time reversal beamforming (TRBF) and implement it for target detection using the minimum-variance distortionless response (MVDR) structure. Through theoretical analysis, computer simulation, and experimental data processing, we have reached the following results:

(a) The TR focusing acquires the channel/environment information from the forward process with a probe source (PS), and then matches the original channel/environment in the backward process. The whole process in essence is a *Bartlett* processing, which makes us generalize the concept of beamforming, and turn TR into TRBF naturally. TRBF is somewhat robust due to the invariance of both the TR solution of the wave equation and the dominant localization signature of the propagated signal. Thus, there are great potentials for TRBF to realize target detection in an uncertain environment.

(b) To cope with environment uncertainties, we first build a modeled source (MS) by the *a priori* knowledge to replace the environment-probing PS; then perform a Taylor series expansion using the mismatch of environmental parameters as the independent variable and the mismatch of acoustic field parameters as the dependent variable, so as to model the change of the signal introduced by the mismatch as an additive interference; finally we implement a TRBF method using the MVDR structure, which is robust against the mismatch between the model and the real environment and has the property of high resolution.

(c) A TRBF target detection system is established and evaluated under four parameter mismatch conditions. This system consists of a transmitting TRBF steered by an MS and an MVDR receiving TRBF with diagonal loading. The feasibility and validity are demonstrated by the results of simulations and experimental data processing.

(d) Transmitting-receiving-united MVDR/GSC (Generalized Sidelobe Canceller) TRBF target detection system is established as an iterative system, and it is a simplified version to realize the MVDR TRBF system mentioned above. Simulation and experimental results show that after one iteration, the performances of TR focusing and target detection are improved under all four mismatch conditions.

Three-dimensional propagation and scattering around a conical seamount

Henrik Schmidt and Wenyu Luo
Department of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, MA 02139, Fax: (617) 253-2350. E-mail: henrik@mit.edu

A three-dimensional propagation and scattering model is developed for an offset acoustic source in an ocean with axisymmetric bathymetry. Based on the same theoretical foundation as the formulation presented by Taroudakis [M. I. Taroudakis, J. Comput. Acoust. 4, 101-121 (1996)], the present approach combines a spectral decomposition in azimuth with a coupled-mode theory for two-way, range-dependent propagation. However, the earlier formulations were severely limited in terms of frequency, size and geometry of the seamount, the seabed composition, and the distance between the source and the seamount, and were therefore severely limited in regard to realistic seamount problems. Without changing the fundamental theoretical foundation, this approach applies a number of modifications to the numerical formulation, leading to orders of magnitude in numerical efficiency for realistic problems. Further, by using a standard normal mode model for determining the fundamental modal solutions and coupling matrices, and by applying a simple superposition principle, the computational requirements are made independent of the distance between the seamount and the source and receivers, and dependent only on the geometry of the seamount and the source frequency. Therefore, realistic propagation and scattering scenarios can be modeled, including effects of seamount roughness and realistic sedimentary structure. Numerical examples show that strong mode coupling may occur at the boundary of a seamount. In addition, coherent artificial backscatter can be diffused in the model by the use of stair steps of random horizontal step sizes, which results in a faster convergence rate in terms of the number of ring-shaped sectors. [*Work supported by the Office of Naval Research.*]

Acoustic remote sensing of the seabed using ambient noise

Martin Siderius
Electrical and Computer Engineering Department, Portland State University, Portland, OR, 97201

Sonar system performance has been observed to vary by location. In many cases this is due to the different seabed types that exist in the world's oceans. Sound interacting with a highly reflective seabed can propagate to much longer distances than for absorbing bottoms. Therefore, knowing the seabed type can lead to much better prediction of how sound will propagate and therefore how the sonar system will perform (i.e., better prediction of sound transmission loss). The seabed reflectivity is quantified with the bottom loss (BL) curve, which describes the sound losses as a function of bottom grazing angle. Factors that influence bottom loss are the physical properties of the seabed such as compressional sound speed, density, and attenuation constant. An additional bottom loss complication is often caused by different materials forming layers, which leads to frequency dependence.

The importance of mapping the bottom loss at various locations has led to a variety of remote sensing techniques. Most methods use projectors or explosives as sound sources to interrogate the seabed and measure the reflected sound. However, methods have been developed that use the naturally occurring ambient noise field as a sound source. The ambient noise is generated from breaking waves on the surface of the ocean, which forms a sheet of noise sources. This sheet of noise sources can be thought of as a type of overhead "acoustic light" that illuminates the seabed. The resulting noise field can be processed either coherently (cross-correlations in the pressure field domain) or incoherently (using sound intensity). There are many practical advantages to using these noise sensing methods: 1) Only receivers are required which simplifies measurements, 2) noise sources emit over a broad band of frequencies, 3) there are no environmental restrictions since these techniques only listen to naturally occurring sound, and 4) information can be extracted directly from measurements without the need for inverse methods. And perhaps most importantly, noise based remote sensing results have produced surprisingly good characterizations of the seabed. In this presentation, the techniques will be described for extracting information about the seabed including reflectivity, layering and the critical angle. Results from several experiments will also be presented.

An experiment on passive synthetic aperture time reversal communications in shallow water

Bingwen Sun and Shengming Guo
Institute of Acoustics, Chinese Academy of Sciences, Beijing, 100190

Time reversal can focus in both time and space. The temporal focusing properties have been used in underwater acoustics communications. Typical passive time reversal communication experiments use a vertical array of receivers and a sound source. The property that a horizontal time reversal array focuses well in the temporal domain indicates the utility of synthetic aperture time reversal. Passive synthetic aperture processing works by repeatedly emitting the same signal from a moving ship and recording the received signal using one or more receivers. Passive synthetic aperture time reversal communication techniques are presented and applied to results from a sea trail. The experiment consisted of a towed hydrophone and a vertical array. During the experiment, a probe signal is emitted to sample the transmit function to be used by time reversal processing. Due to the moving of the hydrophone, Doppler shift compensation and receive waveform synchronization must be performed before time reversal processing. The signal-to-noise ratio is increased and the temporal side lobes are decreased in the time reversal process. Additional communication algorithms can be appended after the time reversal process to increase performance. The result from the at-sea experiment confirms the ability of passive synthetic time reversal communications.

Overview of mid-frequency sound propagation in the Shallow Water 2006 experiment

Dajun Tang
Applied Physics Laboratory, University of Washington, Seattle, WA 98105 USA

Measurements of mid-frequency (1–10 kHz) sound propagation are presented at ranges 1–9 km in a shallow water channel. The source and receivers were placed near the sound axis. Environmental measurements include in situ sediment sound speed and 2D CTDs from a towed CTD chain. Ambient internal waves contributed to field fluctuations. Findings are (1) mean intensity can be well modeled, (2) uncertainty of the intensity field is dominated by water column variability, and (3) the scintillation index is saturated even at the short distance of 1 km.

Transport theory for shallow water propagation with rough boundaries

Eric I. Thorsos, Frank S. Henyey, W.T. Elam, T. Brian Hefner, Stephen A. Reynolds, and Jie Yang
Applied Physics Laboratory, University of Washington, Seattle

At frequencies of about 1 kHz and higher, forward scattering from a rough sea surface (and/or a rough bottom) can strongly affect shallow water propagation and reverberation. The need exists for a fast, yet accurate method for modeling such propagation where multiple forward scattering occurs. A transport theory method based on mode coupling will be described that yields the first and second moments of the field. This approach shows promise for accurately treating multiple forward scattering in one-way propagation. The method is presently formulated in two space dimensions, and Monte-Carlo rough surface PE simulations are used for assessing the accuracy of transport theory results. [*Work supported by ONR Ocean Acoustics.*]

Extraction of the waveguide invariant from a shallow water acoustical experiment

Ling-ai Tian, Shihong Zhou, and Fuchen Liu
Hangzhou Applied Acoustic Research Institute, Hangzhou city, 310012, China

In an oceanic acoustic waveguide, a spectrogram as a function of frequency and range is a visual representation of sound intensity with multiple-path interference. The waveguide invariant describes the dispersive propagation characteristics of the field. It also relates the modal group and phase velocities of normal modes. In this paper, one approach using an image processing and signal processing technique for extraction of the waveguide invariant from striations in the spectrogram is presented, and the accuracy is analyzed. Waveguide invariant values at different receiver depths are extracted using shallow water acoustical experimental data.

Low-frequency seabed sound speed and attenuation inversion using explosive sound source signals in the Yellow Sea

Lin Wan, Ji-Xun Zhou, and Peter H. Rogers
School of Mechanical Engineering, Georgia Institute of Technology, Atlanta, GA 30332

A joint China–U.S. underwater acoustics experiment was conducted in the Yellow Sea with a very flat bottom and a strong and sharp thermocline. About 300 38-g TNT explosive sources and 15 1000-g TNT explosive sources were deployed both above and below the thermocline along two radial lines up to 57.2 km in length and a quarter circle with a radius of 34 km. Two inversion schemes are used to obtain the seabottom sound speed. One is based on extracting normal mode depth functions from the cross-spectral density matrix (CSDM). The CSDM is constructed from explosive signals measured using a 32-element vertical line array at a fixed long range. The other is based on the best match between the calculated and measured modal arrival times for different frequencies. The inverted seabottom sound speed is used as a constraint condition to extract the seabottom sound attenuation by two methods. In the first method, the seabottom sound attenuation is estimated by minimizing the difference between the theoretical and measured modal amplitude ratios. The second method is based on finding the best match between the measured and modeled transmission losses (TLs). The inverted bottom attenuation exhibits apparent nonlinear frequency dependence, which is similar to the low-frequency seabed attenuation data obtained at 20 locations in different coastal zones around the world [Zhou, Zhang, and Knobles, J. Acoust. Soc. Am. 125, 2847–2866 (2009)]. The measured TLs as a function of range, frequency and depth are in good agreement with the predictions based on the inverted seabottom acoustic parameters. [*Work supported by ONR.*]

A robust separating and tracking method on two wideband sources by subspace rotation with one vector hydrophone

Dejun Wang and Fenghua Li
National Laboratory of Acoustics, Institute of Acoustics, Chinese Academy of Sciences, Beijing, 100190, Email: wdj@mail.ioa.ac.cn

It has been proved theoretically that two incompletely correlated sources can be identified by linear signal processing methods. However, it is difficult in practice. A new method is described in this paper to separate two wideband sources with one vector sensor. The method uses a combination of subspace rotation and spatial matched filtering. Simulations show that this method is insensitive to initial azimuth error, independent of the signal spectrum, and superior to the wideband focusing subspace method at low SNR. The results of a sea trial show the validity of the method, which can be used to separate and track two wideband sources under water. [*This work was supported by the Natural Science Foundation of China (10734100).*]

Extension of the coupled-mode method to waveguides with an elastic bottom

Ning Wang+ * and Hao Zhong Wang +
+ Department of Ocean Technology
**Department of Physics*
Ocean University of China, 238 Songling Rd. Qingdao, P.R.China, 266003

Normal mode theory is an exact wave theoretical approach to the acoustic propagation problem in a horizontally layered waveguide. Pierce extended normal mode theory to handle gradual range dependent environments, and derived a continuous system of differential equations for coupled modes. Over the last few decades, the coupled mode method has been developed for various aspects. However, most of treatments have been limited to the fluid bottom case. Modeling elasticity in the ocean bottom has become important in recent years because of a renewed emphasis on shallow water acoustic propagation. Elasticity can be important, in particular, at low frequencies and for sources and receivers close to the ocean bottom; in these cases interface modes of propagation may dominate. In this paper, the coupled-mode method is extended to waveguides with smoothly varying fluid-elastic interfaces. The result is remarkably different from the fluid bottom in several aspects. The boundary conditions imposed at fluid-elastic interfaces gives rise to terms including unknown boundary values so that the differential system for coupled modes is not closed. To make the system closed, additional compatibility and constraining conditions have to be imposed. An explicit form of mode orthogonality in stratified fluid-elastic waveguides is derived; however, it cannot be used for orthogonal decomposition as usual. Some technical remarks on the spectral decomposition of elastic P-SV fields in layered media are also given.

A shallow water reverberation model based on bottom reflection parameters

Jinrong Wu, Erchang Shang, and Tianfu Gao
Institute of Acoustics, The Chinese Academy of Sciences, Beijing, 100190

In general, bottom backscattering is the key factor for shallow water reverberation. The traditional reverberation models need many geoacoustic parameters to describe the bottom and bottom backscattering information. A set of bottom reflection parameters P and Q was suggested by Shang to replace the geoacoustic parameters. This set of parameters can describe well shallow water propagation at middle to long ranges. A shallow water reverberation average intensity model is established based on P and Q in this paper. A comparison between the new reverberation model and the energy flux reverberation model shows that the two reverberation models are equivalent. The PQ reverberation model was used to explain Yellow Sea reverberation data. Experiment data and model predictions agree well. An inversion algorithm is also proposed in this paper, and the bottom reflection parameters P and Q were inverted from reverberation data successfully.

Spread-spectrum acoustic communication

Shengjun Xiong and Shihong Zhou
Hangzhou Applied Acoustic Research Institute, Hangzhou, 310012, China

Multiusers within the same channel as well as low probability of intercept (LPI) have drawn attention to spread spectrum communication. The processing gain (PG) and match filter gain (MFG) of PN sequences in spread spectrum communication are studied and compared. Analysis of the effects of low SNR, Doppler, inter symbol interference (ISI), and underwater acoustic channel variability on spread spectrum communication are presented. A report is given on the experiment design and on two experimental results in shallow water for spread spectrum communication with different PG. Some conclusions will serve as a basis for future work that focuses on multiusers performance and LPI for underwater networks.

Data-model comparisons for wind-generated surface waves from the ASIAEX East China Sea Experiment

Jie Yang
Applied Physics Laboratory, University of Washington, Seattle, WA, USA
Ji-Xun Zhou and Peter H. Rogers
School of Mechanical Engineering, Georgia Institute of Technology, Atlanta, GA, USA

During Asian Sea International Acoustic Experiment (ASIAEX), surface directional wave spectra were recorded for nine consecutive days. Data are analyzed in this paper to show the characteristics of the surface wave field in the East China Sea. Three models, Pierson-Moskowitz, JONSWAP (JOint North Sea Wave Project), and Toba, are evaluated and compared with the ASIAEX root-mean-square surface waveheight data. The data-model comparison, though preliminary, suggests that the JONSWAP-Mitsuyasu model is the best fit to the experimental results. Using wave age, U/c_p, as a sorting parameter, the model performance can be improved by a combined model, JONSWAP-Mitsuyasu for U/c_p <0.8 and Toba-Donelan for U/c_p >0.8. As an example of the application of these results to acoustic propagation, the surface reflection loss factor, using different spectrum models, is shown as a function of wind speed and frequency.

An inversion method of geoacoustic properties based on a towed tilted line array in shallow water

Kunde Yang, Yuanliang Ma, Xuegang Li, and Haibin Qiu
Institute of Acoustic Engineering, Northwestern Polytechnical University, Xi'an, 710072, P. R. China (e-mail: ykdzym@nwpu.edu.cn)

Geoacoustic properties are very important for underwater acoustic field prediction and passive localization in shallow water. The many existing inversion methods generally use a vertical line array to receive the sound signals at a stationary platform, which is not convenient for operation over a large sea area with high resolution. In recent years, matched field inversion based on a towed line array has been studied with increasing interest, and this approach has the prominent advantage of obtaining geoacoustic parameters from a moving platform. Matched field inversion can estimate the geometric parameters accurately because of their strong sensitivities, but it has weak ability to determine the bottom density and attenuation.

A reflection-loss inversion method has been described in the literature for inverting bottom parameters with high resolution using a moving impulsive source and a stationary array. This inversion method has strong sensitivity to bottom density, sound speed, and thickness. However, it can obtain the geoacoustic parameters only for local sea areas.

This paper describes a method for extracting seabed reflection losses based on using a towed line array over large scale sea areas and giving high resolution. The method uses a towed tilted line array and three acoustic sources to cover a large range of grazing angles (from 10° to 70°). The simulation results for shallow water show that different arrays require different experimental configurations in order to cover the same range of grazing angles. The vertical line array must operate with several acoustic sources and requires a stationary platform for the array. The towed horizontal line array needs only one acoustic source but requires a large aperture line array. The towed tilted line array combines the merits of the vertical line array and the horizontal line array, and can invert for the seabed acoustic parameters while moving with high resolution, and requires only a small aperture line array. The error resulting from the distortion of the array shape was analyzed for the inversion method.

Based on a towed tilted line array, a multi-step inversion scheme based on reflection-loss inversion and matched field inversion for the seabed acoustic parameters is presented. The method uses the PPD (posterior probability density) and inversion results from a previous inversion as prior information for subsequent inversion. In the first stage, matched-field inversion is carried out to infer the geometric parameters and the sensitive geoacoustic parameters. Then, from the resulting PPD, the maximum a posteriori (MAP) values of the geometric parameters are used to extract the bottom reflection losses. Finally, based on the reflection-loss inversion, the geoacoustic parameters are determined with the accurate geometric parameters and narrower search bounds of the geoacoustic parameters obtained with the previous inversion.

Distant bottom reverberation in shallow water

Shi-e Yang
College of Underwater Acoustics Harbin Engineering University, Harbin 150001, China

The method of coupled modes is introduced for the investigation of bistatic distant bottom reverberation for an impulsive source in shallow water; this method will be consistent with the principle of reciprocity in all cases. The method of multi-poles for a directional source is also introduced. It is shown that in the case of a layered medium, the intensity of bistatic bottom reverberation will decease according to the cubic power of receiving time *t* and the transverse spatial correlation of bottom reverberation is a little greater than the longitudinal correlation for equal separation of receivers, and both vary in form with the receiving time.

Temporal coherence of normal modes in an ocean waveguide

T.C. Yang
Naval Research Laboratory, Washington, DC 20375

Temporal coherence is a measure of sound correlation in time, and the temporal coherence time refers to the time it takes for the signal to become uncorrelated. Over 20 experiments have been conducted over the past 40 years to measure the temporal coherence of sound propagation to a long distance. The experimental results in shallow and deep water were recently analyzed by Yang [J. Acoust. Soc. Am, 120, 2595-2614 (2006), 124, 113-127 (2008) and 125, 1247 (2009)]. A theoretical treatment is given in this paper for the temporal coherence of normal modes using the path integral approach and also the perturbation expansion of the coupled normal-mode equation to the first order of sound-speed-perturbation squared. For a typical shallow water and deep water environment with internal waves present, the coherence time of the acoustic field (averaged over the source and receivers depths) decreases as -3/2 power of frequency due to mode coupling, as is observed in data. Not including mode-coupling, the coherence time of the acoustic field decreases as -1 power of frequency, same as that predicted for acoustic rays. The coherence time decreases as -1/2 power of range in all cases. [*Work supported by the Office of Naval Research.*]

T-matrix formulation of scattering by an obstacle near a planar sediment boundary and application to detection using iterative time reversal

Yingzi Ying and Li Ma
Institute of Acoustics, Chinese Academy of Sciences, 21 Beisihuanxi Road, Beijing 100190, China, Email: yingyz05@mails.gucas.ac.cn

In this paper, the transition matrix (abbreviated by *T*-matrix) formulation for scattering is adapted to the case of an obstacle immersed in a fluid half-space and in proximity to a planar interface. The *T*-matrix maps the vector of the expansion coefficients of the incident field to that of the scattered field. Upon selecting the complete orthonormal basis set, the *T*-matrix is just related to the geometry and material parameters. The formulation indicates the multiple scattering effects between the obstacle and interface, which may result in super-resonant phenomena. The presence of interface reverberation and a low signal-to-noise ratio hinder the detection of an obstacle resting on it. To form an iterative time reversal process, the time reversal echo is adopted as the new interrogation pulse for the next iteration. Because the iterative time reversal process will lead echoes to converge to a narrowband signal that corresponds to a scattering object's dominant resonance

mode, we investigate the mitigation of the methods difficulties by exploiting the resonances. An at-sea experiment in bottom target detection using single channel iterative time reversal has been performed in the Yellow Sea, China, and the results illustrate the feasibility of the method. [*Work supported by the Chinese Academy of Sciences Innovation Fund through grant CXJJ-260*.]

Sound speed profile inversion in shallow water using a parallel genetic algorithm

Yanxin Yu [1,2, 3] and Zhenglin Li [1,2]
[1] Haikou laboratory, Institute of Acoustics, Chinese Academy of Sciences, Haikou 570105, China,
[2] National Laboratory of Acoustics, Institute of Acoustics, Chinese Academy of Sciences, Beijing 100190, China
[3] Graduate University, Chinese Academy of Sciences, Beijing 100190, China

The sound speed profile and bottom parameters play important roles in shallow water sound propagation, and much attention has been paid on how to obtain them. For comparison with in situ measurements, many inversion methods, for example matched field inversion, have been put forward to invert for the sound speed profile from acoustic signals. However, matched field inversion may be too time consuming in the replica field calculation. The feasibility and robustness of an acoustic tomography scheme with matched field processing in shallow water are studied. The sound speed profile is described by empirical orthogonal functions (EOFs). The acoustic signals from a vertical line array in ASIAEX2001 East China Sea are analyzed to invert for the sound speed profile combined with the estimated EOFs. A parallel genetic algorithm is adopted as the optimization algorithm to increase the inversion speed. The results show that the inverted sound speed profiles are in good agreement with CTD measurements. Moreover, posteriori probability analysis is used to verify the validity of the inverted results. [*Work supported by the Knowledge Innovation Program of the Chinese Academy of Sciences, Grant No. KZCX1-YW-12-2 and the National Natural Science Foundation of China under Grant No. 10734100.*]

Active matched-field localization by a horizontal line array

Yan Zhang [1,2] and Fenghua Li [1]
[1] National Laboratory of Acoustics, Institute of Acoustics, Chinese Academy of Sciences, Beijing 100190, China
[2] Graduate University, Chinese Academy of Sciences, Beijing 100190, China

The technique of matched-field processing (MFP) can be used in active target localization. The possibility of active matched-field localization by a horizontal line array is investigated via simulation and experiments. In the simulation, a rigid ship is modeled as a reflector and the scattered signal in the underwater channel is calculated. The ship can be localized in range, depth and azimuth by a Bartlett matched-field processor. In an experiment, explosive echo signals were received by a horizontal line array. With the signals, the target ship can be localized by a broadband matched-field processor. The signal to noise ratio (SNR) of MFP is increased in comparison with the conventional plane-wave beam forming. The simulated and experimental results indicate that it is capable to conduct active matched-field localization with echo signals observed by a horizontal array. [*Work supported by National Natural Science Foundation 10734100.*]

Improvement of longitudinal correlation of explosive signals by using waveguide invariance

Yanjun Zhang[1, 2], Fenghua Li[1], and Xiaoxing Su[3]
[1] National Laboratory of Acoustics, Institute of Acoustics, Chinese Academy of Sciences [2] Graduate University, Chinese Academy of Sciences
[3] School of Electronics and Information Engineering, Beijing Jiaotong University

Longitudinal correlation is a very important parameter in underwater acoustic signal processing. Normal mode interference is often the dominant effect in the decrease of the low frequency longitudinal correlation coefficient. Based on waveguide invariance, a method has been developed to enhance the correlation between the signals recorded by two horizontally separated hydrophones [see Su Xiaoxing et al., Improvement of the longitudinal correlations of acoustical field by using the waveguide invariance, Acta Acoustica, 31(4), 305-309, 2006]. In this research, the method is applied to another experimental data set. It differs from the former related work in that the signal is produced by an explosive source, which is more complicated than a bulb source due to the strong bubble pulse following the shock wave, and which also has a slowly varying spectrum. The results show that the spatial correlation of low frequency signals received by the horizontal array can evidently be improved. [*This work was supported by the Natural Science Foundation of China (10734100).*]

Uncertain field modeling and robust source localization in shallow water

[1,2]HangFang Zhao, [1,2]XianYi Gong, and [1]ZiBin Yu
[1]Hangzhou Applied Acoustics Research Institute, Hangzhou City, Zhejiang Province, China
[2]Department of Information Science & Electronic Engineering,
Zhejiang University, Hangzhou City, Zhejiang Province, China

Oceanic environmental uncertainty can cause significant performance degradation of SONAR systems. Understanding and modeling the uncertainty propagating from the environment to the acoustic field is necessary in SONAR design and operation to mitigate the uncertainty effect, and hence to robustly detect and localize targets. The statistical properties of the uncertainty can be described by the probability density functions (pdf) of the environmental parameters and the acoustic field. Using the pdfs of the environmental parameters and the acoustic field, we employ the polynomial chaos basis functionals to stochastically represent the uncertainty of both the environment and the acoustic field, and then embed the uncertainty into the wave equation to propagate the acoustic field and its uncertainty simultaneously. A low rank covariance matrix of the signal propagating in uncertain environments is finally constructed and consequently used to detect and localize targets. Sonar signal processing can be generalized to beamforming by using a quadratic operation of fitting the covariance matrix of replica signals to that of array data. To mitigate the uncertainty, the beamforming adopts an ellipsoidal sphere model to form a steering vector space, which guarantees the minimum gain constraint. The covariance matrix and ellipsoidal sphere model are simple and effective descriptions of the overall shape of the distributions of points in multiple dimensional Euclidean space, and thus the consistency benefits robust detection and localization. The uncertain ellipsoidal sphere constraint can be reduced to a second cone constraint to realize the resolution of robust beamforming. After theoretic and simulation analysis, the data collected by a vertical array in a shallow water test are applied to source localization.

Effective geophysical parameters for seabed geoacoustic models from low-frequency measurements

Ji-Xun Zhou and Xue-Zhen Zhang
Georgia Institute of Technology, Atlanta, GA 30332-0405, USA and
Institute of Acoustics, The Chinese Academy of Sciences, Beijing 100190, China

The seabed is the king of the shallow-water (SW) acoustics problem. Low-frequency (LF) sound speed and attenuation in sand and silt seabottoms have recently been analyzed and summarized from long-range field measurements in shallow water [Zhou, Zhang and Knobles, J. Acoust. Soc. Am., 125(5), 2847-2866, 2009]. Field measurements conducted at 20 locations in different coastal zones around the world were analyzed. Half of these measurements were made in the Yellow Sea and the East China Sea. The seabed attenuations, inverted from different acoustic field characteristics, exhibit similar magnitude and nonlinear frequency dependence below 2000 Hz at all of these sites. The present paper shows that both LF field-derived sound speed and attenuation in the bottom can be equally well described by the Biot-Stoll model, the Buckingham VGS model, the Chotiros–Isakson BICSQS model, or the Pierce-Carey simplified model. The effective geophysical parameters for each of these four seabed acoustic models are derived. The shear wave speed and attenuation in the top layer of the sand-silt bottoms are also estimated in the 50–500-Hz range from the LF measurement-derived sound speed and attenuation. The results indicate gaps in current seabed acoustics research. More communication is needed between investigators of LF geoacoustic inversion and those modeling sediment acoustics. More communication is required between groups working in the low- and mid-high frequency SW acoustics in order to develop a practical and reliable seabed geoacoustic model. [*Work supported by ONR and CAS.*]

An approach to measure the acoustic impedance of sediment in shallow water based on multi-path theory

Xian Zhu, Zhongkang Wang, and Huiliang Ge
Hangzhou Applied Acoustic Research Institute, Box 1249, Hangzhou 310012, China

In shallow water, bottom characteristics are required in some mode-based localization approaches like matched field processing. As a common acoustical characterization of the medium, it is valuable to measure the impedance of sea bottom. In theory, the impedance of sea bottom is a product of density and sound speed, and relates to the sound pressure reflection coefficient, as well as the angles of incidence and refraction, but the angle of refraction is hard to get in practice. So some experiments are designed to measure the impedance by measuring the reflection coefficient when the sound wave is incident at the sea bottom interface vertically, in which case the angles of incidence and refraction are both zero. This is done in spite of the fact that the energy of the reflected wave is small because of the large loss when a sound wave is vertically incident to the interface. In this article, an approach to measuring the sea bottom sediment's density and sound speed using a short vertical array in shallow water is derived based on multi-path theory when the sound wave is not at vertical incidence to the interface. Through the analysis of simulated and real experimental data, the sediment's density and sound speed can be measured correctly.

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